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ESG NORTH FINDER INTEGRATION SYSTEM

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Research on the GPS Platform-Based
ESG North Finder Integration System

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Abstract: The GPS platform-based ESG north finder
integration scheme, which is a new scheme to achieve
north seeking on its own and is of practical value, is
presented in this paper. It has the advantages of
better mobility, high accuracy, quick alignment,
identification of the ESG drift models in real time.

Key words: GPS, platform ESG north finder, azimuth
angle

1. Introduction

In modern land combat technology, emphasis has been
increasingly placed on mobility and flexibility because raising
the mobility of armed forces and impact point hit rate becomes
one of the key measures in self protection. Owing to the high
cost and powerful kill ability of a missile, accurate positioning
and direction finding is expected to be conducted for the weapon
system before a missile is launched so as to accurately destroy
the potential targets. At present, the azimuth alignment adopted
for flying missiles uses launch pad alignment and optical
alignment, while ballistic missiles generally employ an optical
pointing technique. The launch pad alignment, however, can
provide only a lower precision with an azimuth alignment error
reaching 1-10[1], while optical alignment, though reaching a
certain precision at an angular second level, is poor in mobility
and takes as long as 0.5-1h to accomplish an alignment, suitable

only for a launch site with a known geographic location and target azimuth, and it is apt to expose itself.

To raise the concealment ability and mobility, missiles are expected to perform north finding on their own and with a higher precision at a launch site with an unknown geographic location in as short a time as possible. A platform static electricity gyro north finder plan presented in the References [2] possesses the capability of realizing self north finding in a short time but requires the geographic location of the launch vehicle to be known. To solve this problem, other auxiliary positioning equipment has to be applied, such as GPS, etc. A high precision satellite navigation system vigorously developed in the United States, GPS can provide various users with information of high precision three-dimensional location, three-dimensional velocity and accurate time, and is widely applied in aviation, aerospace, sea voyage, vehicle navigation and geodesy. Once GPS is combined with the platform static electricity gyro north finder to form an integrated system, it can realize accurate positioning and direction finding with a mobile missile launch pad.

This paper presents a brief introduction of the principle of the GPS/platform static electricity gyro north finder, which, by using the approximate non-linear filtering theory, can identify the azimuth angle of the system, the location of the launch pad and the gyro drift model coefficient. Also, it can carry out a theoretical analysis of the azimuth angle error generated by the latitude error. The study shows that this integration system, with a higher north finding precision, serves as a new plan of realizing azimuth alignment during a mobile missile launch and has applications in engineering.

2. Principle of the GPS/Platform Static Electricity Gyro North Finder Integration System

The principle of the GPS/platform static electricity gyro

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north finder integration system is shown in Fig. 1. The static electricity gyroscope is mounted on a servo rotating base plate with its gyro shell rotating around the rotor momentum matrix axis at an angular velocity ω_b; θ and α respectively are corners of the outer ring axis and inner ring axis of the rotating floor; $\theta=\alpha=0$ at the initial instant, U_g is the information output by GPS receiver; γ is azimuth angle. When the alignment time is no more than 20min, the variation law of and α caused by the Earth's rotation is [2]:

$$\begin{bmatrix} \dot{\theta} \\ \dot{\alpha} \end{bmatrix} = \begin{bmatrix} 0 & -\omega_2 \\ \omega_2 & 0 \end{bmatrix} \begin{bmatrix} \theta \\ \alpha \end{bmatrix} + \omega_1 \begin{bmatrix} \sin\gamma \\ \cos\gamma \end{bmatrix} + \begin{bmatrix} \epsilon_x \\ \epsilon_y \end{bmatrix} \tag{1}$$

where ω_1 and ω_2 are north and vertical components of the Earth's rotation angular velocity ω_s, $\omega_1=\omega_s\cos\varphi$, $\omega_2=\omega_s\sin\varphi$, ω_s, where ω_y is gyro drift. From the References [6], the expressions of ω_z and ω_y can be derived as:

$$\begin{bmatrix} \omega_z \\ \omega_y \end{bmatrix} = \begin{bmatrix} S & C & aC^2 & aS^2 & 2\theta SC & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & S & C & \theta C^2 & \theta S^2 & 2a\,SC \end{bmatrix} A$$
$$+ \begin{bmatrix} -S & -C \\ C & -S \end{bmatrix} \begin{bmatrix} e_x \\ e_y \end{bmatrix} \tag{2}$$

where S=sin ω_bt, S=cos ω_bt, A=$[a_1a_2a_3a_4a_5b_1b_2b_3b_4b_5]^T$ is constant state vector; e_x and e_y are Guassian white noise of zero mean value.
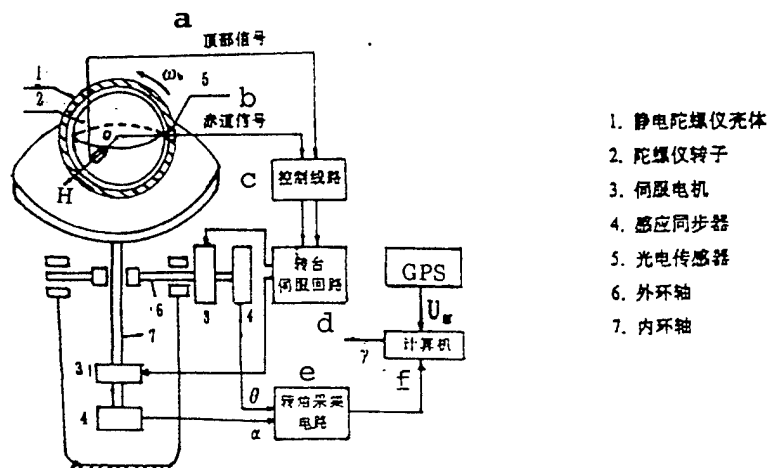
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Fig. 1. Principle of GPS/Platform
Static Electricity Gyro North Finder

Key:
(a) Top signal
(b) Equator signal
(c) Control circuit
(d) Rotating floor servo circuit
(e) Corner collection circuit
(f) Computer
1. Static electricity gyroscope shell
2. Gyroscope rotor
3. Servo electric machine
4. Induction synchronizer
5. Photoelectric sensor
6. Outer ring axis
7. Inner ring axis

Equations (1) and (2) indicate that the variation law of θ and α is associated with user's latitude ϕ, azimuth angle γ and gyro drift. Also, the simultaneous Eqs. (1) and (2) take the state of the GPS receiver into consideration. In this case, the state equation of the integration system can be derived as follows:

$$\dot{x}(t)f[X(t)]+[(t)W(t)] \tag{3}$$

where $X(t)=[\theta\alpha\gamma,a_1a_2a_3a_4a_5b_1b_2b_3b_4b_5x_g]^T$, $W(t)=[\varepsilon, \varepsilon, \varepsilon,]^T$,

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x, ε, are the state vector and noise of GPS receiver, $f[X(t)]$, $[(t)]$ are given different values for different integration modes. The observation equation of the system is

$$Y(t)=H[X(t)]+V(t) \qquad (4)$$

where $Y(t)$ is the swept observation space, $V(t)$ is observation noise. The specific forms of $H[X(t)]$ and $V(t)$ will be detailed later.

If the action of ω_x and ω_y is omitted, the azimuth error $\delta\gamma$ caused by latitude error $\delta\varphi$ can be derived from Eqs. (1) and (2) as

$$|\delta\gamma| \approx \frac{2}{\sin 2\varphi}|\mathrm{tg}\gamma\delta\varphi| \qquad (5)$$

Obviously, in domestic regions, the selected φ value usually will not be too small, and $\delta\varphi$ will generate a larger $\delta\gamma$ when γ is larger and therefore, it is necessary to conduct accurate positioning for the launch pad.

With a higher positioning precision, GPS is an ideal system used for positioning. With a horizontal positioning error 100m at present, this system, if combined with the platform static electricity gyro north finder, will be extremely useful in increasing north finding precision. Different GPS receiver models output different information. When the output information is the user's longitude and latitude and altitude, the implications of parameters in the state equation (3) and observation equation (4) respectively are:

$$X(t)=\begin{bmatrix} \theta & a & \gamma & a_1 & a_2 & a_3 & a_4 & a_5 & b_1 & b_2 & b_3 & b_4 & b_5 & \varphi \end{bmatrix}^T \qquad (6)$$

$$f[X(t)]=\begin{bmatrix} \omega_2 a-\omega_1\sin\gamma+a_1 S+a_2 C+a(a_3 C^2+a_4 S^2)+2\theta a_5 SC \\ -\omega_2\theta-\omega_1\cos\gamma+b_1 S+b_2 C+\theta(b_3 C^2+b_4 S^2)+2a\, b_5 SC \\ 0_{12\times1} \end{bmatrix} \qquad (7)$$

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$$\tau(t) = \begin{bmatrix} -S & -C \\ C & -S \\ O_{12 \times 2} \end{bmatrix} \tag{8}$$

$$W(t) = [\varepsilon_x \varepsilon_y]^T \tag{9}$$

$$H[X(t)] = [\theta \ \alpha \ \varphi]^T \tag{10}$$

$$V(t) = [V_\theta V_\alpha V_\varphi]^T \tag{11}$$

where V_θ, V_α and V_φ are Guassian white noise of zero mean value, while other parameters have the same implications as above.

When the GPS receiver outputs pseudo range information and user attitude can be ignored, the implications of parameters in state equation (3) and observation equation (4) respectively are:

$$X(t) = [\theta \alpha \gamma \ a_1 a_2 a_3 a_4 a_5 \ b_1 b_2 b_3 b_4 b_5 \ \varphi \lambda t_\omega t_{ru}]^T \tag{12}$$

$$f[X(t)] = \begin{bmatrix} \omega_2 \alpha - \omega_1 \sin\gamma + a_1 S + a_2 C + \alpha(a_3 C^2 + a_4 S^2) + 2\theta a_5 SC \\ -\omega_2 \theta - \omega_1 \cos\gamma + b_1 S + b_2 C + \theta(b_3 C^2 + b_4 S^2) + 2\alpha b_5 SC \\ O_{13 \times 1} \\ t_{ru} \\ -\beta t_{ru} \end{bmatrix} \tag{13}$$

$$\tau(t) = \begin{bmatrix} -S & -C & 0 & 0 \\ C & -S & 0 & 0 \\ O_{13 \times 4} \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{14}$$

$$W(t) = [\varepsilon_x \ \varepsilon_y \ \varepsilon_{t\omega} \ \varepsilon_{tru}]^T \tag{15}$$

$$H[X(t)] = [\theta \alpha \ \rho_1 \rho_2 \cdots \rho_n]^T \tag{16}$$

$$V(t) = [V_\theta V_\alpha V_1 V_2 \cdots V_n] \tag{17}$$

where t_W and t_{ru} respectively are the range error when the user clock error is equivalent to clock frequency drift error, and the range variation rate; λ is user longitude; $\rho(i=1,2\ldots,n)$ is pseudo range between user and satellite i; n is number of visible quantities; $V_i(i=1,2\ldots,n)$ is pseudo range observation noise; other parameters have the same implications as above. The expression of pseudo range ρ is

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$$\rho_i = [(X_s - R_s \cos\varphi \cos\lambda)^2 + (Y_s - R_s \cos\varphi \sin\lambda)^2 + (Z_{si} - R_s \sin\varphi)^2]^{1/2} + l_s$$

(18)

where (X_{si}, Y_{si} and Z_{si}) is the location of the satellite i in Earth's coordinates, which can be calculated from the sidereal data provided by GPS receiver.

The non-linear time-varied system made of the state equation and observation equation of the integration system has no available analytical solutions and should be analyzed by using the numerical calculation method. In the study of the integration system with the approximately non-linear filtering theory, the initial azimuth angle during the missile launch, the coefficients of gyro drift model and the accurate location information of the missile launch pad can be identified. The parameter identification process is as follows:

$$\hat{X}_{i+1/i} = \hat{X}_{i/i} + f(\hat{X}_{i/i})T_0 + A(\hat{X}_{i/i})f(\hat{X}_{i/i})T_0^2/2$$

(19)

$$P_{i+1/i} = \Phi_i P_{i/i} \Phi_i^T + \tau_i Q_i \tau_i^T$$

(20)

$$K_{i+1} = P_{i+1/i}H_{i+1}^T(H_{i+1}P_{i+1/i}H_{i+1}^T + R_{i+1})^{-1}$$

(21)

$$\hat{X}_{i+1/i+1} = \hat{X}_{i+1/i} + K_{i+1}[Y_{i+1} - H(\hat{X}_{i+1/i})]$$

(22)

$$P_{i+1/i+1} = [I - K_{i+1}H_{i+1}]P_{i+1/i}$$

(23)

where $A(\hat{X}_{i/i}) = \partial f[x(t)]/\partial x(t)|x(t) = \hat{X}_{i/i}$, $H_{i+1} = \frac{\partial}{\partial x(t)}H[x(t)]|X = \hat{X}_{i+1/i+1}$

$\Phi_i = I + A(\hat{X}(t_{i/i})T_0 + \frac{\partial}{\partial x(t)}\{A[x(t)]f[x(t)]\} \cdot \frac{T_0^2}{2}$ $\tau_i = \tau(t_i)$, $\hat{X}_{i+1/i+1}$ $Y_{i+1} = Y$

(t_{i+1}), $Q_i = E[W(t_i)W^T(t_i)]$ $R_{i+1} = E[V(t_{i+1})V^T(t_{i+1})]$,
T_0 is sampling time; recursion initial value is $X_{0/0}$, $P_{0/0}$.

3. System Simulation and Its Result Analysis

Suppose a missile launch pad arrives at an unknown launch site with true longitude and latitude $\lambda = 118^0$, $\varphi = 32°$, while a target under attack is stationary, located at north to east 20°. A GPS receiver will output longitude and latitude and altitude information; recursion initial value $\hat{X}_0 = 0, P_0, Q_i, R_i$; the element values on the diagonal line are respectively listed in Tables 1 and 2; other elements are zero.

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Table 1. Element Values on P_z diagonal line

单位 [1]	$(")^2$		(o/h^2)	$(")^2$
i	1 2	3 4 5 6 7 8 9 10 11	12 13	14
$P_z(i,i)$	0.5² 4²		0.001²	10²

Key: (1) Unit

Table 2. Element Values on θ_k, R_k Diagonal Line

单位 [1]	(o/h^2)		$(")^2$		
i	1	2	1	2	3
$Q_k(i,i)$	0.001²				
$R_k(i,i)$			0.5²	0.3²	3.5²

Key: (1) Unit

Table 3 lists the accurate coefficient values of the gyro drift model: sampling time $T_0=0.5S$; azimuth alignment time is 20min; gyro actual body rotation angle velocity $\omega_b=\pi/h$; the forms of the parameters in the state equation and observation equation of the system are selected from Eq. (6). Based on the system performance analysis, the stable estimated values of azimuth angle and latitude are computed as:

$$\hat{\gamma} = 20.003° \qquad \hat{\varphi} = 32.0001°$$

The stable estimated values of the coefficients a_i, $b_i (i=1,2,3,4,5)$ of the gyro drift model are listed in Table 3. Figs. 2-4 show the $\hat{\gamma}, \hat{a}_1, \hat{a}_2, \hat{b}_1, \hat{b}_2$ variation curves in the process of identification.

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Table 3.   Coefficients of Gyro Drift Model

单位 1		o/h				单位			o/h		
i	1	2	3	4	5	i	1	2	3	4	5
a_i	0.1	0.2	0.4	0.4	0.4	$\hat{a}_i$	0.106	0.193	0.325	0.306	0.510
b_i	0.6	0.7	0.5	0.5	0.5	$\hat{b}_i$	0.592	0.680	0.422	0.581	0.565

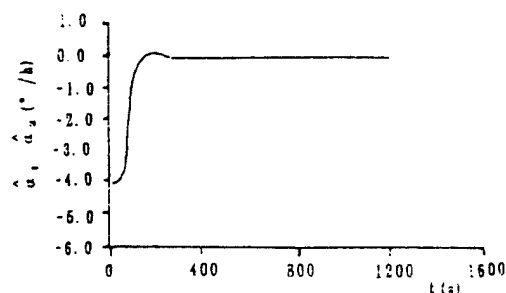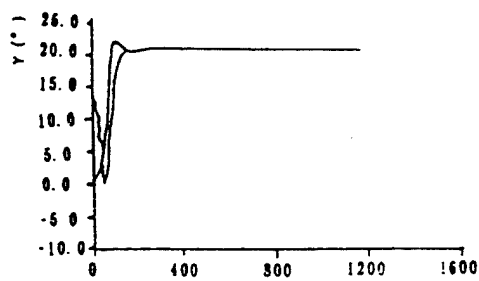Key: (1) Unit

Fig. 2. Azimuth Angle Curve

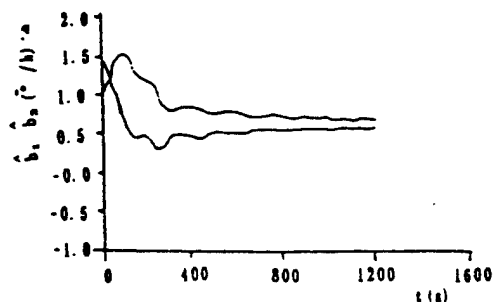Fig. 3. $\hat{a}_1, \hat{a}_2$ Curves

Fig. 4.2 $\hat{b}_1, \hat{b}_2$ Curves

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The system simulation result shows that based on the location information output by the GPS receiver, the azimuth angle and the location of the missile launch vehicle at the initial missile pointing can be more accurately estimated by using Kalman filtering theory with an azimuth error around 10" and latitude error around 0.4", indicating a rather high north finding precision. In addition, this integration plan also allows a real-time identification of the gyro drift model to solve the problem of poor repetition of the drift model coefficients when the static electricity gyros start one by one. Undoubtedly, this is extremely helpful in raising the north finding precision of the system. Therefore, the GPS/platform static electricity gyro north finder plan presented in this paper appears to be a new plan of realizing self north finding during mobile missile launch, and it is also applicable to other occasions which need accurate north finding.

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